Delayed pointing movements to masked Müller–Lyer figures are affected by target size but not the illusion

Matthieu de Wit, John van der Kamp, Rich S.W. Masters

Institute of Human Performance, University of Hong Kong, 111-113 Pokfulam Road, Hong Kong SAR, China
Research Institute MOVE, Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands

Abstract

There is ongoing debate with respect to interpretation of the finding that, in contrast to perceptual size judgments, actions are relatively unaffected by the Müller–Lyer illusion. In normal unrestricted viewing situations observers cannot perform an action directed at an object without simultaneously perceiving the object – this makes it difficult to unequivocally establish whether observed effects are a function of vision for perception, vision for action, a combination of both, or of a single all-purpose visual system. However, there is evidence that observers are capable of performing actions towards objects of which they are not consciously aware, implying that two distinct visual thresholds may exist; one accompanying vision for action and one accompanying vision for perception. To investigate this possibility we created a situation in which visual information was presented below the perception threshold, but above the purported action threshold, allowing examination of action responses independent of contributions from vision for perception. Following a perceptual categorization task, participants performed delayed pointing movements towards briefly exposed masked Müller–Lyer targets of different sizes. When the targets were presented below the perception threshold, participants were unable to discriminate between them, yet their delayed pointing movements were affected by target size (but not the illusion). The results imply that vision for action is functional even after a delay and/or that the pickup of egocentric information is associated with a lower visual threshold than the pickup of allocentric information.

1. Introduction

Goodale and Milner (1992) and Milner and Goodale (1995, 2008) proposed that the perception of objects and the visual control of actions directed at those objects are mediated by two functionally and anatomically distinct visual systems (i.e., vision for perception and vision for action). In a paradigm that has been used extensively to examine this proposal, participants perform perception and action responses upon targets embedded in geometrical illusions such as the Müller–Lyer illusion. Meta-analyses indicate that unlike perceptual judgments, actions performed in unrestricted viewing situations are relatively unaffected by (but not immune to) the Müller–Lyer illusion (e.g., Bruno, Bernardis, & Gentilucci, 2008; Bruno & Franz, 2009). Milner and Goodale (1995, 2008; Ganel, Tanzer, & Goodale, 2008; Goodale & Haffenden, 1998) explain these findings by arguing that vision for action involves a different (i.e., allocentric) visual threshold, while vision for action relies mainly on allocentric (i.e., world-centered) information. Gentilucci, Chieffi, Daprati, Saetti, and Toni (1996; see also Hu & Goodale, 2000; Westwood & Goodale, 2003; Westwood, Heath, & Roy, 2000) examined the kinematics of delayed pointing movements directed at occluded Müller–Lyer figures. Restriction of vision by occluding the goal target led to an increase in the effect of the illusion to a level comparable to effects normally associated with perceptual judgments. This use of (retained) allocentric information has been taken to imply that delayed actions are mediated by vision for perception and that vision for action only engages in guiding actions when they are performed online (i.e., in real time) and in full vision (Goodale, Westwood, & Milner, 2004).

Ongoing controversy exists with respect to the interpretation of the differential effect of geometrical illusions on perception and action. Several authors have proposed that the relative immunity of actions to geometrical illusions when compared to perceptual measures can be explained by differences in task characteristics between commonly used action and perception tasks, and does not implicate different visual processes (i.e., vision for action and vision for perception) underlying the execution of those tasks. Smeets, Brenner, de Grave, and Cuijpers (2002; see Schenk, 2006 for a related argument) argued that the spatial attributes that are used to perform a task determine susceptibility to an illu-
sion. de Grave, Brenner, and Smeets (2004), for example, found that pointing movements along the shaft of a Müller–Lyer figure (emphasizing the use of size information, which is affected by the illusion) were influenced by the illusion whereas pointing movements perpendicular to the shaft (emphasizing endpoint position information, which is unaffected by the illusion) were not. Franz, Hesse, and Kollath (2009), varied the amount of visual feedback available to participants during the execution of grasps directed at Müller–Lyer targets. Removing feedback at movement onset, at 1/3 of the transport phase and at 2/3 of the transport phase led to a gradual reduction of the illusion effect that was directly related to the amount of available visual feedback. Based on these results, Franz et al. (2009) argued that the increased effect of illusion after a delay is caused by the availability of visual feedback leading to online corrections of the movement (and not by a shift in control from vision for action to vision for perception).

In unrestricted viewing situations, observers cannot perform an action directed at an object without simultaneously perceiving the object (Milner & Goodale, 2008; see also Enns & Liu, 2009; van Doorn, van der Kamp, de Wit, & Savelsbergh, 2009). This makes it difficult to unequivocally determine whether observed illusion effects are a function of vision for perception, vision for action, a combination of both, or of a single all-purpose visual system. However, a possible resolution to this problem might exist. There is evidence that vision for action has quicker access to visual information than vision for perception. Perissa, Arzi, and Rossetti (1998; see also Veerman, Brenner, & Smeets, 2008) asked participants to perform reach movements towards stimuli that could be perturbed in either location or color during the ongoing movement. In case of a perturbation, participants were required to stop their movement. Results showed that stop-responses to perturbations of color, an object property that would arguably be picked up by vision for perception, were initiated about 80 ms later than stop-responses to location changes, which are arguably guided by vision for action (Rossetti, Perissa, & Pelisson, 2000). Heath, Maraj, Godbolt, and Binsted (2008; Binsted, Brownell, Vorontsova, Heath, & Saucier, 2007; Heath, Neely, Yakimishyn, & Binsted, 2008; and see Cressman, Franks, Enns, & Chua, 2007 for a related experiment) asked participants to perform pointing movements towards masked briefly exposed (i.e., 13 ms) targets of different sizes. Although participants were unable to perceptually discriminate between targets at above chance levels, Fitts' law (1954) was preserved in that the movement time for pointing movements towards smaller targets was longer. Notably, these movements were not performed online but after a delay of up to 2 s. These findings suggest that (1) vision for action may remain functional at lower minimum stimulus exposure times than vision for perception and (2) vision for action may be capable of guiding actions performed after a delay. The current experiment was designed to exploit this potential difference in visual threshold between vision for action and vision for perception by creating a situation in which participants performed an action task and a perception task in response to Müller–Lyer targets. Based on the evidence that vision for perception influences the illusion on perceptual measures, see Bruno et al., 2008; Bruno & Franzi, 2009; Ganel et al., 2008) together with the assumption that the briefly exposed targets were not expected to exceed the vision for perception threshold, we only expected an effect of illusion on the delayed pointing movements for the targets exposed for long durations, not for targets exposed for brief durations.

2. Methods

2.1. Participants

Seventeen right-handed participants (8 females) aged 23–60 years (33 ± 10) with normal or corrected-to-normal vision participated in the experiment. They were naïve with regard to the purpose of the experiment and were treated in accordance with the ethical guidelines of the local Institution.

2.2. Materials

Stimuli were presented on a 19 in. CRT-monitor (Philips Brilliance 190P4) with a refresh rate of 65 Hz and a resolution of 1024 × 768 pixels using E-Prime 2.0 presentation software (Psychology Software Tools, Pittsburg, PA). An Optotak 3020 motion analysis system (Northern Digital, Waterloo, Ontario) was used to measure the extent of the pointing movements by recording the position of an infrared light emitting diode placed on the tip of the right index finger with a frequency of 200 Hz. Stimuli consisted of three different lengths (short: 11.5 cm, medium: 14.5 cm, long: 17.5 cm) of wings out and wings in Müller–Lyer figures and neutral figures (i.e., without wings). The lines that made up the figures (shag and wings) were 5 mm wide. The wings had a length of 3 cm and an angle of 45° relative to the shaft. Stimuli were presented randomly in six locations (top-left, center-left, bottom-left, top-right, center-right, bottom-right) but appeared equally often on the left and right side and top, center and bottom of the computer screen (see Fig. 1).

2.3. Procedure and design

Participants performed an action task and a perception task. In the action task, participants were instructed to place the tip of their right index finger on a fixation dot that was presented at one end of the to-be-presented target shaft and to fixate their gaze on the tip of their finger (see Fig. 1). If the dot appeared at the left side of the screen, a movement from the left end of the target shaft to the right end of the target shaft was required, and vice versa. The dot was present for 3 s after which the target stimulus was presented. Stimulus exposure duration was either brief (12 ms) or long (1500 ms) and pointing movements had to be made either as quickly as possible after stimulus offset (RT delay) or after a delay of 2000 ms following stimulus offset, in both cases indicated by an auditory start signal (i.e., for RT delays the start signal sounded at stimulus offset and for 2000 ms delays the start signal sounded 2000 ms after stimulus offset). Stimulus presentation was always followed by a mask that was presented for 200 ms and consisted of an array of scrambled target stimuli (see Fig. 1). Participants were required to maintain gaze fixation upon the tip of their finger until they heard the start signal. For the pointing movements, the instruction was to “point as fast and accurately as possible to the target stimulus, which is located at the far right end of the horizontal shaft line when you hear the beep”. The combination of the factors stimulus exposure duration and movement delay led to a total of four action conditions (i.e., 12 ms stimulus exposure × RT/2000 ms movement delay and 1500 ms stimulus exposure × RT/2000 ms movement delay) which were performed in separate blocks by each participant in counterbalanced order.

To assess whether participants were able to categorize the target stimulus at 12 ms stimulus exposure duration, participants performed a perception task both before and after the four action blocks. The conditions in the perception task were identical to those in the action task but instead of making a pointing movement participants indeed presented below the vision for perception threshold, participants were first required to indicate the size of the briefly exposed targets in a perception task. In four subsequent action conditions, participants made pointing movements along the shaft of the targets that were presented for brief (i.e., 12 ms) or long durations (i.e., 1500 ms) either as soon as possible after target stimulus offset (i.e., reaction time (RT) delay) or after a delay of 2 s. We expected pointing movements to be scaled to target length regardless of whether they were briefly presented (i.e., below the vision for perception threshold) or not – as long as target stimulus duration exceeded the vision for action threshold.

We also had specific expectations with respect to the effect of the illusion on pointing movements directed at the briefly exposed Müller–Lyer targets. Based on the evidence that vision for perception relies mainly on the use of allocentric information (e.g., as implicated by the relatively large effects of the Müller–Lyer illusion on perceptual measures, see Bruno et al., 2008; Bruno & Franzi, 2009; Ganel et al., 2008) together with the assumption that the briefly exposed targets were not expected to exceed the vision for perception threshold, we only expected an effect of illusion on the delayed pointing movements for the targets exposed for long durations, not for targets exposed for brief durations.

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were now required to indicate whether they had seen a short, medium or long target stimulus by pressing a corresponding key on the keyboard. Participants were encouraged to respond fairly quickly (i.e., within 1–3 s after stimulus offset).

In each action and perception block, each stimulus type (wings out/wings in/no wings) in combination with each length (short/medium/long) was randomly presented two times leading to a total of 18 experimental trials (i.e., 3 stimulus types × 3 lengths × 2 repetitions) per block. To maintain active engagement in the experiment despite the very high task difficulty in the 12 ms stimulus duration action blocks and the perception blocks, experimental trials were randomly interspersed with trials in which the stimulus duration was 36 ms instead of 12 ms. In these trials, each stimulus type in combination with the short and long target length was presented once (total 6 trials). Similarly, in the long stimulus duration action blocks experimental trials were interspersed with trials in which the stimulus duration was 1524 ms instead of 1500 ms. Each block thus consisted of 18 + 6 = 24 trials of which only the first 18 experimental trials were analyzed. To familiarize participants with the different stimulus lengths and types and with the task requirements, the experimental blocks were preceded by a practice block of 18 trials in which all stimuli were presented twice and the stimulus duration was 3 s. In this block, the experimenter verbally indicated the length of the presented target in each trial. Participants performed a total of 162 trials. There was a 5 min break between the third and the fourth block and the experiment was completed in approximately 1 h.

2.4. Data analysis

For the perception task, we first computed the percentages of correct responses. To assess whether group performance in the perception task was at chance levels, the percentages of correct responses were submitted to a one-sample t-test and tested against a test value of 33.3% (i.e., chance). Furthermore, to examine whether individual participants were able to discriminate between stimulus lengths at above chance levels, for each participant the number of correct responses were entered in a Z-score proportions test (see Eq. (1), where $c$ is the number of correct responses). The critical Z-value for $\alpha = .05$ lies between 1.64 and 1.65. A Z-score greater than 1.65 was therefore interpreted as an indication that the participant was performing above chance levels. To examine whether errors made by participants were influenced by the illusion-inducing wings that were present in a subset of the stimuli, we recorded the direction of the errors made in response to the Müller–Lyer stimuli. For both wings in and wings out stimuli the number of errors that corresponded with the direction of the illusion (i.e., the stimulus was categorized respectively as smaller than the presented stimulus and as larger than the presented stimulus) and the number of errors that did not correspond with the direction of the illusion was determined. To test for an effect of illusion on the errors, the number of corresponding and noncorresponding errors was submitted to a proportions test ($Z$-test). A lack of difference between the two blocks ($t(16) = 1.23$, $p = .236$) indicates that no perceptual learning occurred over the course of the experiment (39.2 and 43.5% correct for the first and second perception block, respectively). Group categorization performance in the two perception blocks differed significantly from chance level performance ($t(16) = 2.81, p < .05$). We therefore entered the score of each individual into a proportions test ($Z$-test) to identify participants who were able to categorize the stimuli above chance levels at 12 ms stimulus exposure time. Because an increase in the number of trials leads to more reliable estimates of proportions and there was no difference in performance between the first and the second perception block, the total amount of correct responses of the 36 trials from the two perception blocks were entered in the proportions test. Out of the seventeen participants, six (3 females) performed above chance levels (see Fig. 2). For these participants the brief stimulus duration (12 ms) exceeded the vision for perception threshold. As we were interested in pointing movements towards stimuli presented below the vision for perception threshold, we excluded these participants from the pointing movement analysis.

To assess whether the illusion-inducing wings that surrounded a subset of the stimuli influenced the categorization errors of the eleven participants who performed at chance levels in the perception task, we compared the number of errors that corresponded with the direction of the illusion with the number of errors that did not correspond with the direction of the illusion. No significant differences existed ($t(10) = 1.44, p = .181$; 82 corresponding errors and 69 noncorresponding errors, on average), indicating that the presence of wings did not have an effect on categorization performance in the perception task.

3.2. Action task

The pointing movement analyses were performed on the eleven participants who performed at chance levels in the perception task. We first conducted a boxplot analysis and identified 12 outliers (corresponding to 1.5% of the total number of data points), which
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is further supported by the fact that the t-test for the coefficient reflecting the extent to which pointing distance differed between wings out and wings in stimuli was significant in both conditions; RT delay, \( t(10) = 5.29, p < 0.0001 \) (slope wings out = 0.968, wings in = 0.869), 2000 ms delay, \( t(10) = 5.58, p < 0.0001 \) (slope wings out = 0.930, wings in = 0.846). A t-test comparing the mean percent corrected illusion effects of the two 1500 ms stimulus exposure conditions revealed no differences between these conditions (RT delay: 10.47%, SD = 7.41, 2000 ms delay: 10.79%, SD = 7.74).

Analysis of the pointing distances in the 12 ms stimulus exposure conditions revealed a rather different pattern (see Fig. 4). Although the one-predictor model explained only a small amount of the variance in these conditions, this model nevertheless showed a significant fit to the data of both the RT delay condition, \( F(1, 186) = 5.91, p < 0.05, R^2 = 0.031 \) (slope = 0.209) and the 2000 ms delay condition, \( F(1, 192) = 10.72, p < 0.01, R^2 = 0.053 \) (slope = 0.264), indicating that pointing movements were significantly scaled to actual target length. However, for these conditions, adding the second predictor to the model did not lead to a significant change in the proportion of explained variance, indicating that at 12 ms stimulus exposure duration, the presence of wings did not have an effect on pointing distance. In fact, for the RT delay condition, adding the predictor stimulus type rendered the model's fit nonsignificant (Model 1, \( p = 0.012 \), Model 2, \( p = 0.121 \)) while for the 2000 ms delay condition, adding the second predictor merely reduced the model's significance (Model 1, \( p = 0.001 \), Model 2, \( p = 0.008 \)). The absence of an effect of illusion at 12 ms stimulus exposure is further supported by the fact that the t-test for the coefficient reflecting the extent to which pointing distance differed between wings out and wings in stimuli was not significant in both conditions. Slopes in the RT delay condition measured 0.088 and 0.305 for wings out and wings in stimuli respectively. In the 2000 ms delay condition they measured 0.334 and 0.428 for wings out and wings in stimuli. The mean percent corrected illusion effect measured 1.50% (SD = 15.82) in the RT delay condition and 2.94% (SD = 13.43) in the 2000 ms delay condition. These effects were not significantly different from each other or from 0%.

4. Discussion

Under the assumption that vision for perception and vision for action remain functional at different minimum stimulus exposure times, we attempted to present target stimuli below the vision for perception threshold but above the vision for action threshold. In a perception and an action task, participants were exposed to masked Müller–Lyer figures (wings out, wings in, no wings) of different lengths for brief (12 ms) or long (1500 ms) durations. Analysis of performance levels in the perception task showed that 6 out of the 17 participants were able to discriminate between stimulus lengths at above chance levels, implying that for these participants the briefly exposed stimuli exceeded the vision for perception threshold. Strikingly, analysis of pointing distances of the remaining 11 participants, for whom the briefly presented stimuli did not exceed the vision for perception threshold, showed that their actions were nevertheless scaled to actual stimulus length. Thus, while participants were exposed to the same set of stimuli, the perception task was accompanied by a higher visual threshold than the action task.

Several studies (i.e., Franz et al., 2009; Gentilucci et al., 1996; Hu & Goodale, 2000; Westwood & Goodale, 2003; Westwood et al., 2000) have reported that the introduction of a delay causes a profound increase in the effect of illusion on actions; this is typically explained as an effect of vision for perception supplanting vision for action (but see Franz et al., 2009). The current study replicates these findings. Pointing movements after a delay were significantly affected by the illusion for targets presented above the vision for perception threshold. This effect was the same for movements performed after a short (i.e., start signal at stimulus offset, RT delay) or a long delay (i.e., start signal 2 s after stimulus offset). However, when targets were presented below the vision for perception threshold, the illusion did not affect pointing distance, both when movements were performed at RT delay and after a delay of 2 s. Together with our finding that pointing movements were nevertheless scaled to physical target length, this may suggest that vision for action is not fully disrupted when movements are performed after a delay.

One might argue that because a subset of the stimuli was surrounded by illusion-inducing wings, the possibility exists that an effect of illusion rather than an inability to perceive the stimuli may have caused the participants to perform at chance levels in the perception task. However, because on average the size of perceptual illusion effects is between 10 and 20% of physical target length (see Bruno et al., 2008; Bruno & Franz, 2009) participants should have been able to discriminate between the targets in our experiment regardless of whether wings were present or not. Moreover, under this assumption the perceptual errors made by participants should have been made in accordance with the direction of the illusion. That is, the size of wings out stimuli should have been overestimated more often than the size of wings in stimuli, and the size of wings in stimuli should have been underestimated more often than the size of wings out stimuli, which was not the case. In addition, participants frequently reported no experience of seeing the stimuli. Notably, the possibility that some participants were in fact able to perceptually discriminate between briefly presented stimuli does potentially apply to the studies by Heath and colleagues (e.g., Binsted et al., 2007; Heath, Maraj, et al., 2008; Heath, Neely, et al., 2008; see also Cressman et al., 2007) who found that Fitts’ law (1954) was preserved for delayed pointing movements towards masked stimuli. In sum, our results provide solid evidence for the existence of distinct task-dependent visual thresholds for the pickup of visual information.

Our results uncover a problem with the common interpretation of the increased effects of illusion on delayed action in which it is argued that delayed actions are necessarily guided by vision for perception (as implied by their dependence on allocentric information; see Franz et al., 2009; Goodale et al., 2004; Hu & Goodale, 2000; Westwood & Goodale, 2003 for a related argument). To our knowledge, this interpretation has never been tested by preventing vision for perception from contributing to actions performed after a delay. The claim is therefore an indirect one and, as evidenced by our finding that delayed pointing movements are scaled to the

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2 Bruno and Franz (2000) have argued that a correction formula incorporating the slope of the function that relates movement distance to target length in the denominator of the fraction might be appropriate when there are differences in scaling between conditions, as is the case for the present 12 and 1500 ms stimulus exposure conditions. Doing so returns corrected percent measures for the 12 ms stimulus exposure time conditions of 9.2% (SD = 74.1) and 12.8% (SD = 70.2) for the RT- and 2000 ms Delay conditions, respectively. However, note the high standard deviations. Clearly, with the relatively high variability in pointing distance at 12 ms stimulus exposure and the lack of a consistent pattern in the relationship between pointing distance and wing orientation, this correction approach produces somewhat misleading percent measures. Accordingly, t-tests show that, despite their apparently large size, the corrected percent measures do not differ from 0% (\( p = 0.310 \) and 0.194, respectively).

3 In stead of examining the discrimination performance of individual participants with proportions tests, these authors examined discrimination performance at the group level with (one-sample) t-statistics or analysis of variance. It is possible that while these tests did not show an overall effect, some participants may in fact have been able to discriminate between the masked stimuli above chance levels. In the current experiment, we removed such participants from the pointing movement analysis.
veridical size of Müller–Lyer targets presented below the vision for perception threshold, may have to be revisited.

Evidence against the notion that vision for action is capable of guiding delayed actions that is not subject to the above criticism comes from a study of patient D.F., who has damage to the ventral stream (i.e., the anatomical substrate of vision for perception) but has an intact dorsal stream (i.e., the anatomical substrate of vision for action). Although she is well able to grasp visible objects, her ability to accurately grasp objects after a delay is completely disrupted (Goodale, Jakobson, & Keillor, 1994). However, in a recent study D.F. displayed preserved performance in a perception task that depended on the use of egocentric information and impaired performance in an action task that depended on the use of allocentric information, implying that her deficit may be task (i.e., perception or action) independent and instead related to an inability to exploit allocentric information (Schenk, 2006). A similar, information based (as opposed to task based), distinction may account for the results obtained in the current experiment. Closer inspection of our perception task shows that it could only be performed by relying on allocentric information. Categorization necessarily required a comparison of the length of the presented stimulus with the recalled length of previously presented stimuli, thus leaving participants no choice but to use allocentric information. Both the chance level categorization performance and the significant negative correlation between the amount of time that was spent looking at the target shaft (containing the pertinent sources of egocentric information for grasping) and the size of the illusion on perceptual length estimations disappears when participants are instructed to ignore the wings (i.e., the allocentric information). van Doorn et al. (2009) examined the gaze behavior of participants engaged in a perceptual length estimation task and a grasping task directed at Müller–Lyer stimuli. Results showed a significant negative correlation between the amount of time that was spent looking at the target shaft (containing the pertinent sources of egocentric information for grasping) and the size of the illusion effect on hand aperture in both the grasping task and the perceptual length estimation task, showing that in either task participants had the potential to rely on egocentric information. As a third and final alternative, our findings are in accordance with the possibility that there exists both a distinction in threshold between vision for perception and vision for action and a distinction in threshold for the pickup of allocentric information and egocentric information. Future experiments are needed to distinguish between the described possibilities and to further examine the interrelationships between vision for perception and vision for action and the pickup of allocentric and egocentric information.

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